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Note

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Validity of negative binomial distribution among the target fragments emitted in high energy h–A interactions

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Abstract Validity of negative binomial distribution is tested for the medium and low energy target fragments emitted in 350 GeV/c π^- - AgBr interactions It is observed that in both the hemispheres, forward and backward and also in whole phase space, the validity is well satisfied This signifies that the mechanism of production of the target fragments is internuclear cascading. Analysis also enlighten the old concept of correlated clusters in terms of cascade phenomena

Keywords π^- - AgBr interactions, negative binomial distribution, target fragments

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It is said that the medium energy grey hadrons and low energy target fragments may carry some interesting background in relativistic nuclear interactions. Till date, there had been a considerable amount of study on these target fragments for h - A and A - A interactions [1]. It is generally believed that they are the low energy part of the internuclear cascade and leave the nucleus during or shortly after the passage of incident nucleus (10^{-22} sec). Since they are produced during the passage of projectile through the heavy target or shortly after the passage, they are expected to remember a part of the history created by the relativistic nuclear collision [1]. Thus, the studies on low or medium energy target fragments received special attention by the experimental high energy physicists. An universal Koba Nielsen Olesen (kNo) type scaling behaviour was also observed [2] among the medium energy target fragments in A-A interactions.

Negative binomial distribution :

During the last few years, a new type of multiplicity distribution among the charged secondary fragments was proposed [3], in order to express the data available in different accelerator energies more precisely, called negative binomial distribution (NBD). Mathematically it is expressed as :

$$P_n(k,n) = \{(n+k-1)/n\}\,(k/\bar{n})^k\,(1+k/\bar{n})^{-(n+k)}. \qquad (1)$$

Here, a new parameter k is introduced. It is related with the dispersion of the distribution $\left(D^2 = \overline{n^2} - \bar{n}^2\right)$ as :

$$\frac{D^2}{\bar{n}^2} = \frac{1}{\bar{n}} + \frac{1}{k}, \qquad (2)$$

where $\bar{n}$ corresponds the average multiplicity of the distribution.

It was explained [3] that NB distribution arises due to cascading between the intra-nuclear particles immediately after the relativistic collision between the target and projectile. In the case of cascading, one can usually define a grouping of particles in clusters. A cluster is formed by the particles originating directly or indirectly from one particle regarded or being originally produced in the collision. In case of medium energy protons emitted in high energy nuclear interactions, there

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are some interesting models [4] which explained that target fragments are really emitted in the form of correlated clusters. Thus, it is obvious that one should try to find a common platform to explain the mechanism of production of these correlated clusters in terms of NB-distribution. If it is found that the target fragments are really obeying NBD, then one may comment that there is some sort of cascading between the target fragments also.

In this note, we have studied the validity of NB-distribution among the target fragments (both for medium and low energy fragments *i.e.* grey and black particles) in π^- - AgBr interactions at 350 GeV/c. Observation extends from whole phase space upto two hemispheres (forward and backward). It is observed that in all the cases, the distributions are in good agreement with the NBD.

The data were taken from the stack of G5 emulsion plates exposed to 350 GeV/c beam at CERN. The emulsion plates were scanned with the help of a Semi automatic scanning system with a Leitz Metallopan microscope using oil immersion objective of magnification 10x and occular lenses of 25x magnification.

Criteria for selecting the events were made according to following :

(i) Interactions were picked up after leaving 3 mm. from the edges of pellicles in order to avoid the directions at the edges.

(ii) The beam track must be at an angle less than 3^0 to the mean beam direction in the pellicle.

(iii) Interactions should not be within 20 μm from the top or bottom surface of the pellicle.

(iv) Selection of the primary interactions were made by following the incident beam track in the backward direction. With the above selection criteria, a sample of 569 events were chosen. Here, nuclear emulsion served the purpose of a target as well as of a detector.

All charged secondaries of these events were classified in the following way :

(a) Black tracks (n_b) were laid by the particles having ranges less than 3 mm and ionisation greater than $6I_0$ where I_0 is the plateau ionisation.

(b) Grey tracks (n_g) were laid by the particles having ranges greater than 3 mm. and ionisation value between $1.4I_0$ to $6I_0$.

(c) Relativistic shower (n_s) particles formed the tracks with ionisation less than 1.4 I_0 were not generally confined within the emulsion pellicile.

To measure the emission angles of the particles, we took readings of the space coordinate (x,y,z) of the production points on the incident beam and two points of each grey track using oil immersion objective of magnification 100x and occular lenses of 25x magnifications. The error in the angular measurement has been estimated to be ~ 0.1 mrad.

Table 1 shows the values of different parameters after fitting the data of medium energy target fragments (grey tracks) with the NBD. Analysis were performed in forward and backward hemispheres in center of mass frame *i.e.* $\theta_{CM} < 90^0$ and $\theta_{CM} \geq 90^0$ as well as in whole phase space. An interesting observation here is average number of clans $\overline{N}(= \bar{n} / \bar{n}_c$, $\bar{n}_c$ being average clan multiplicity) is slightly decreased in backward hemisphere but parameter k has reverse picture with respect to the forward hemisphere.

Table 1. Different parameters $(k, \bar{n}, \overline{N})$ obtained after fitting the data of medium energy target fragments with the NBD in forward hemisphere, backward hemisphere and in whole phase space. Here, ($\overline{N} = \bar{n} / \bar{n}_c$, $\bar{n}_c$ average clan multiplicity) corresponds the number of average clans

Zone of observation	k		$N(= \bar{n} / \bar{n}_c)$	$\chi^2 / d.o.f.$
Forward hemisphere	1 05	2 60	1.31	0 31
Backward hemisphere	1 44	1.78	1 61	0 48
Whole phase space	4 43	4 38	3.04	0 61

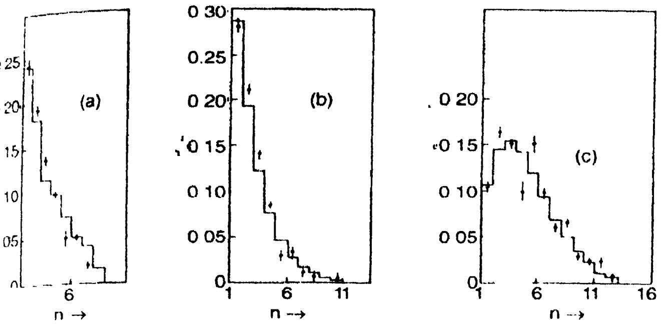
Table 2 shows the values of different parameters after fitting the data of low energy target fragments (black tracks) with the NBD. Here, the interesting observation is that the value of parameter k as well as average clan number $N(= \bar{n} / \bar{n}_c)$ increases to a significant extent in the backward hemisphere $\theta_{CM} < 90^0$ with respect to the forward hemisphere $\theta_{CM} \geq 90^0$

Table 2. Different parameters $(k, \bar{n}, \overline{N})$ obtained after fitting the data of low energy target fragments with the NBD in forward hemisphere, backward hemisphere and in whole phase space.

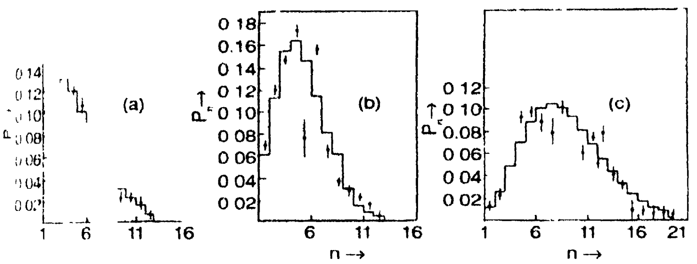
Zone of observation	k	$\bar{n}$	$N(= \bar{n} / \bar{n}_c)$	$\chi^2 / d.o.f.$
Forward hemisphere	3.51	3.91	2.63	0 15
Backward hemisphere	15 84	4.59	4.03	1 44
Whole phase space	9.02	8.50	5.99	1 15

Figures 1(a - c) show the multiplicity distribution of grey tracks in forward hemisphere, backward hemisphere and in whole phase space respectively. Similarly, Figures 2(a - c) show the distribution of black tracks in forward hemisphere, backward hemisphere and in whole phase space, respectively. χ^2 / degree of freedom values for all the distributions are shown in Table 1 and Table 2.

Since in this analysis, a selection was made to choose highest multiplicity events for π^- - AgBr central interaction, thus according to hydrodynamic model [5], a mach shock front should develop due to the collision between a lighter projectile with the heavy target nuclei. Thus in this type of collision, backward hemisphere of the interacting zone of the target is



Figures 1(a-c). Multiplicity distributions of the medium energy target fragments (grey tracks) in (a) forward hemisphere, (b) backward hemisphere and (c) the whole phase space. Histogram shows NBD fitting with the data



Figures 2(a-c). Multiplicity distributions of low energy target fragments (black tracks) in (a) forward hemisphere, (b) backward hemisphere and (c) whole phase space. Histogram shows NBD fitting with the data

expected to be richer in energy density due to hydrodynamic flow of hot nuclear matter (side-splash phenomenon). From the Table 1, we observe that average clan number in both the hemisphere are almost identical, though, the value of k has increased to some appreciable value in the backward hemisphere. It refers that cascading is gradually rising in the backward hemisphere. No significant change observed in the value of average clan number ($\overline{N} = \overline{n} / \overline{n}_c$) of the medium energy fragments (90% of these are expected to be protons), because the protons which are coming from the final state of the reaction in the form of clans, will be interrupted by the heavy target nucleons residing at the outer layers of the target nucleus. Among the members within these clans, few will be successful to overcome this influence (statistically, whose mean free path is greater than the dimension of the target nucleous). Thus, medium energy target fragments are expected to be oriented isotropically in both the hemispheres. There is some possibility that the forward hemisphere may be richer in number by the medium energy target fragments due to relativistic effect, which is clearly reflected by the values of $\overline{n}$ and $\overline{N}$ shown in Table 1. Some of the medium energy target fragments, specially those emerging from the backward hemisphere, will be energised due to the presence of shock wave in this zone. These will scatter a large number of comparatively heavy target fragments from the outer layers of the target nucleus to produce clans of higher multiplicity. This picture is clearly supported in the analysis shown in Table 2. It shows that both k and average clan number ($\overline{N}$) rise to a significant amount in the backward hemisphere.

Above analysis proves that there is indeed some sort of cascading between the medium energy as well as the low energy target fragments emitted in π^- - AgBr interaction at 350 GeV / c. This analysis highlights the old concept of correlated clusters towards the new dimension by introducing the concept of negative binomial distribution among the target fragments emitted in the relativistic h-A interactions.

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